(12) Patent Gazette (A)

(19) Japan Patent Office (JP)

(11) Patent Application Publication Nr.

JP H06-188169

(43) Publ. Date: 8. July 1994

(51) Int. Cl.^{6}	ID Code	Int. Ref. Numb.	FI	Techn. Ind.
H01L 21/027				
G02B 27/28	A	9120-2K		
G03F 7/20	521	7316-2H		
G11B 5/127	D	7303-5D		
		7352-4M	H01L 21/30	

Request for examination: No Claims: 46 (16 pages total)

(21) Appl. Number: JP H05-212198

(22) Appl. Date: 8. Apr. 1993

(31) Number of Prior. Right: H4-247249

(32) Priority Date: 24.Aug., 1992

(33) Priority Country: Japan (JP)

(71) Applicant: 000001007
Canon Corporation
[Addr. Omitted]

(72) Inventor: Yasuyuki Unno*
Canon Corporation
[Addr. Omitted]

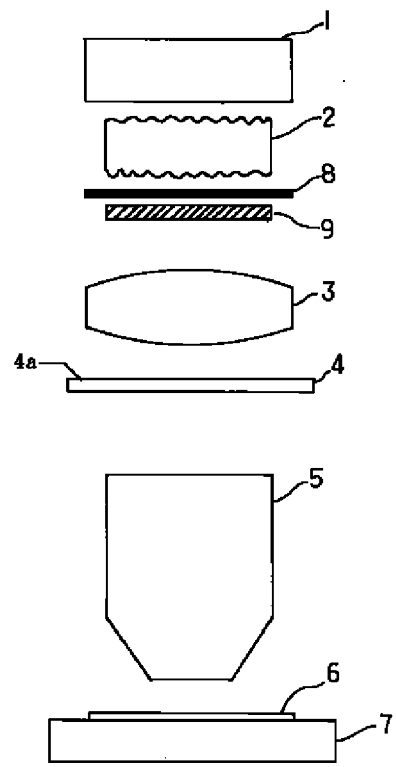
(74) Representative: Yukio Takanashi*

(54) [Title of the Invention] Imaging Method, Exposure Apparatus Using this Method, and Device Manufacturing Method Using this Method

(57) [Abstract]

[Problem] To obtain an imaging method and an exposure apparatus using this method, with which a periodic pattern is projected with high resolution using a light beam having optimum polarization.

[Means for Solving Problem] A periodic pattern on a reticle surface is illuminated with a light beam from an illumination system, and when projecting an image of the pattern onto a wafer surface by causing diffraction light from the pattern to be incident on a pupil of a projection optical system, a linearly polarized light beam having a polarization plane in a direction that is substantially perpendicular to the direction in which the period of the pattern is shortest is selected with a polarization device.



[Patent Claims]

1. An imaging method, characterized in that a line-shaped pattern is imaged with a polarized light beam that is polarized in a longitudinal direction of that pattern.

2. The imaging method of claim 1, characterized in that said pattern is illuminated by said polarized light beam.

3. The imaging method of claim 1, characterized in that said pattern is illuminated by a non-polarized light beam, and said polarized light beam is extracted from a beam from said pattern.

4. The imaging method of claim 1, 2 or 3, characterized in that imaging said pattern is substantially performed with two diffraction beams from said pattern.

5. The imaging method of claim 4, characterized in that the beam for illuminating said pattern is obliquely incident.

6. The imaging method of claim 4, characterized in that said pattern comprises a phase shifter.

7. A device manufacturing method characterized in that a device is manufactured by imaging a line-shaped pattern onto a workpiece with a polarized light beam that is polarized in a longitudinal direction of said lines, and transferring said pattern onto the workpiece.

8. The device manufacturing method according to claim 7, characterized in that said pattern is illuminated by said polarized light beam.

9. The device manufacturing method according to claim 7, characterized in that said pattern is illuminated by a non-polarized light beam, and said polarized light beam is extracted from a beam from said pattern.

10. The device manufacturing method according to claim 7, characterized in that imaging said pattern is substantially performed with two diffraction beams from said pattern.

11. The device manufacturing method according to claim 10, characterized in that the beam for illuminating said pattern is obliquely incident.

12. The device manufacturing method according to claim 10, characterized in that that said pattern comprises a phase shifter.

13. An exposure apparatus, characterized by being configured to illuminate a line-shaped pattern by an illumination means with a polarized light beam that is polarized in a longitudinal direction of said pattern, and to project and expose said pattern illuminated by the polarized beam from said illumination means with a projection means onto a substrate.

14. The exposure apparatus of claim 13, characterized in that said illumination means causes said polarized light beam to be obliquely incident on said pattern.

15. An exposure apparatus, characterized by being configured to illuminate a line-shaped pattern by an illumination means with a non-polarized light beam, and to project and expose said pattern illuminated by the non-polarized beam from said illumination means onto a substrate with a polarized beam that is polarized in a longitudinal direction of said pattern by a projection means.

16. The exposure apparatus of claim 15, characterized in that said illumination means causes said non-polarized light beam to be obliquely incident on said pattern.

17. An imaging method, characterized in that a repeating pattern is imaged with a polarized light beam that is polarized in a direction substantially perpendicular to the direction in which a repeating period is smallest.

18. The imaging method of claim 17, characterized in that said pattern is illuminated by said polarized light beam.

19. The imaging method of claim 17, characterized in that said pattern is illuminated by a non-polarized light beam, and said polarized light beam is extracted from a beam from said pattern.

20. The imaging method of claim 17, characterized in that said pattern includes a pattern made of lines and spaces.

21. The imaging method of claim 17, characterized in that said pattern includes a pattern of dot shapes.

22. The imaging method of claim 17, 18, 19, 20 or 21, characterized in that imaging said pattern is substantially performed with two diffraction beams from said pattern.

23. The imaging method of claim 22, characterized in that the beam for illuminating said pattern is obliquely incident.

24. The imaging method of claim 22, characterized in that said pattern comprises a phase shifter.

25. A device manufacturing method characterized in that a device is manufactured by imaging a repeating pattern onto a workpiece with a polarized light beam that is polarized in a direction substantially perpendicular to the direction in which the repeating period is smallest, and transferring said repeating pattern onto the workpiece.

26. The device manufacturing method according to claim 25, characterized in that said pattern is illuminated by said polarized light beam.

27. The device manufacturing method of claim 25, characterized in that said pattern is illuminated by a non-polarized light beam, and said polarized light beam is extracted from a beam from said pattern.

28. The device manufacturing method of claim 25, characterized in that said pattern includes a pattern made of lines and spaces.

29. The imaging method of claim 25, characterized in that said pattern includes a pattern of dot shapes.

30. The imaging method of claim 25, 26, 27, 28 or 29, characterized in that imaging said pattern is substantially performed with two diffraction beams from said pattern.

31. The imaging method of claim 30, characterized in that the beam for illuminating said pattern is obliquely incident.

32. The imaging method of claim 30, characterized in that said pattern comprises a phase shifter.

33. An exposure apparatus, characterized by being configured to illuminate a repeating pattern by an illumination means with a polarized light beam that is polarized in a direction substantially perpendicularly to the direction in which the repeating period is smallest, and to project and expose said pattern illuminated by the polarized beam from said illumination means with a projection means onto a substrate.

34. The exposure apparatus according to claim 33, characterized in that said illumination means causes said polarized light beam to be obliquely incident on said pattern.

35. An exposure apparatus, characterized by being configured to illuminate a repeating pattern by an illumination means with a non-polarized light beam, and to project and expose said pattern illuminated by the non-polarized beam from said illumination means onto a substrate with a polarized beam that has been polarized in a direction substantially perpendicular to the direction in which the repeating period is smallest by a projection means.

36. The exposure apparatus according to claim 35, characterized in that said illumination means causes said non-polarized light beam to be obliquely incident on said pattern.

37. An image projection method, characterized in that a pattern with periodicity is illuminated by a light beam of linearly polarized light corresponding to the direction of periodicity of the pattern, and the pattern is projected by a projection optical system onto a predetermined surface.

38. An image projection method, characterized in that a pattern with periodicity is illuminated by a light beam of linearly polarized light having a polarization plane that is perpendicular to a direction in which the pattern is arranged, diffraction light from the pattern is incident onto a pupil of a projection optical system, and the pattern is projected onto a predetermined surface.

39. An image projection method, characterized in that a pattern with periodicity is illuminated, through a polarization device that can change a light beam from an illumination system into linearly polarized light as desired and emit the polarized light beam, by a light beam having a polarization plane that is substantially perpendicular to a direction in which the pattern's period is shortest, diffraction light from the pattern is incident onto a pupil of a projection optical system, and the pattern is projected onto a predetermined surface.

40. An exposure apparatus, characterized by illuminating a pattern with periodicity on a reticle surface with a light beam from an illumination system, wherein, when an image of the pattern is projected onto a wafer surface by causing diffraction light from the pattern to be incident on a pupil of a projection optical system, the pattern is illuminated with a linearly polarized light beam having a polarization plane in a direction that is substantially perpendicular to a direction in which the period of the pattern is shortest.

41. An image projection method, characterized in that a pattern with periodicity is illuminated, and when projecting the pattern onto a predetermined surface with a projection optical system, it is projected with a linearly polarized light beam corresponding to a direction of periodicity of the pattern.

42. An image projection method, characterized in that a pattern with periodicity is illuminated, and when the pattern is projected onto a predetermined surface by causing diffraction light from the pattern to be incident on a pupil of the projection optical system, it is projected with a linearly polarized light beam having a polarization plane in a direction perpendicular to a direction in which the pattern is arranged.

43. An image projection method, characterized in that a pattern with periodicity is illuminated with a light beam from an illumination system, and when the pattern is projected onto a predetermined surface by causing diffraction light from the pattern to be incident on a pupil of the projection optical system, the projection of the pattern is performed by selecting, with a polarization device, a light beam having a polarization plane in a direction that is substantially perpendicular to a direction in which the period of the pattern is shortest.

44. An exposure apparatus, characterized in that a pattern with periodicity on a reticle surface is illuminated with a light beam from an illumination system, and when an image of the pattern is projected onto a wafer surface by causing diffraction light from the pattern to be incident on a pupil of a projection optical system, it is projected by selecting, with a polarization device, a linearly polarized light beam having a polarization plane in a direction that is substantially perpendicular to a direction in which the period of the pattern is shortest.

45. A semiconductor device manufacturing method, characterized by including a step of preparing a reticle having a circuit pattern, and a wafer, and a step of exposing/transferring a circuit pattern of the reticle onto the wafer with the method of any of claims 37, 38, 39, 41, 42 and 43.

46. A semiconductor element, characterized in that it is manufactured with the manufacturing method of claim 45.

[Detailed Description of the Invention]

[0001]

[Field of Industrial Application]

The present invention relates to an imaging method as well as to an exposure apparatus using this method and a device manufacturing method using this method.

[0002] In particular, the present invention relates to an imaging method that is advantageous for manufacturing such devices as ICs or LSIs, CCDs, liquid crystal panels or magnetic heads, as well as to an exposure apparatus using this method and a device manufacturing method using this method.

[0003] The present invention also relates to an image projection method that illuminates with a suitable light beam an electronic circuit pattern (pattern) with small line width on the surface of a reticle or mask (referred to below as "reticle") in a stepper, which is an apparatus for manufacturing semiconductor elements, and that can project images with high resolution onto a wafer surface, as well as to an exposure apparatus that uses this image projection method.

[0004]

[Conventional Technology] As the requirements for greater integration of semiconductor chips, such as ICs or LSIs, grow higher, there have been various improvements in order to increase the resolving power of so-called steppers (reducing projection exposure apparatuses), which perform reduced projection and transfer of a circuit pattern that is illuminated by UV light.

[0005] Conventionally, as methods for increasing the resolving power, such methods as enlarging the numerical aperture (NA) of the reducing projection lens system and shortening the wavelength of the exposure light have been employed. Moreover, as alternative methods, methods that are in particular advantageous for imaging periodic microscopic patterns (repeating microscopic patterns) have been proposed recently, such as the phase shift method and the oblique incidence illumination method.

[0006] The following is an explanation of the imaging of microscopic patterns with periodicity.

[0007] Fig. 32 is a graph showing a repeating pattern made of three microscopic slits, where the horizontal axis of the graph denotes a pattern position X and the vertical axis denotes an amplitude transmittance T. In the drawing, the portion

with a transmittance of 1 lets light pass, whereas the portion with a transmittance of 0 blocks light.

[0008] When a repeating pattern with such an amplitude transmittance is illuminated with coherent light, then the incident light is split up into diffraction light of 0-order, +1st order, -1st order and higher orders. Of these, only the diffraction light that is incident on a pupil of the projection optical system contributes to forming an image, and ordinarily, the 0-order, +1st-order and -1st-order diffraction light is incident on the pupil of the projection optical system.

[0009] Fig. 33 is a diagram showing the amplitude of the 0-order and ±1st-order diffraction light at the pupil. The numerals 100, 101 and 102 in the drawing respectively denote the peak positions of the 0-order, +1st-order and -1st-order diffraction light, and IA denotes the amplitude.

[0010] Fig. 34 shows the intensity distribution of a pattern image that is formed by the 0-order and ±1st-order diffraction light. The vertical axis denotes the intensity I. In ordinary imaging, when the line width of a pattern becomes extremely small and only 0-order diffraction light is incident on the pupil of the projection optical system, this will already make formation of the pattern image impossible.

[0011] With the phase shift method, on the other hand, the repeating pattern is designed in such a manner that when the light passes through the repeating pattern, the phases of the diffraction light from neighboring slits are shifted by 180°, so that the 0-order diffraction light component does not appear on the pupil of the projection optical system, and the pattern image is formed by the +1st-order and -1st-order diffraction light.

[0012] Fig. 35 shows an amplitude distribution that results on the pupil of the projection optical system when a repeating pattern made of three microscopic slits is projected with the phase shift method. The numerals 103 and 104 in the drawing respectively indicate the peak positions of the +1-st and -1st-order diffraction light components. In this case, if the repeating period of the pattern is the same, then the distance between the peak positions 103 and 104 will be half the distance between the peak positions of the ±1st-order diffraction light in Fig. 33. Using the phase shift method, it is possible to make the apparent spatial

frequency of patterns smaller, so that the ±1st-order diffraction light from even tinier patterns enters the pupil. Consequently, the resolution can be increased.

[0013] The amplitude distribution on the pupil shown in Fig. 33 is for the case that the light is incident from a direction that is perpendicular to the plane on which the pattern is rendered, whereas in the oblique incidence method, the position of the amplitude distribution is shifted to the lateral direction by letting the light be incident from a direction oblique to this plane.

[0014] Fig. 36 is a diagram showing an amplitude distribution on the pupil when light is obliquely incident on the repeating pattern in such a manner that the 0-order and the +1st-order diffraction light is incident on the pupil. The numerals 105 and 106 in the drawing respectively denote the peak positions of the 0-order and the +1st-order diffraction light.

[0015] When trying to form an image with the two kinds of diffraction light shown in Fig. 36, then also with the oblique incidence method, as in the case of the phase shift method, the diffraction light from even tinier patterns can reach the pupil, increasing the resolution.

[0016]

[Problems to be Solved by the Invention] It has become clear from the results of a simulation performed by the inventors that if a pattern with periodicity is illuminated for the effect of raising the resolution with the above-described phase shift method or the oblique incidence illumination method, then the polarization state of the light has a large influence. Therefore, there is the problem that when the polarization state of the illumination light is not made optimal for the pattern, then a large increase of the resolution cannot be attained even when using the phase shift method or the oblique incidence illumination method.

[0017] It is thus an object of the present invention to provide an imaging method that is favourably improved for imaging microscopic patterns, an exposure apparatus using this method, as well as a method for manufacturing a device using this method.

[0018] Furthermore, it is an object of the present invention to provide an image projecting method that is suitable for manufacturing semiconductor devices, with which, when projecting a pattern with periodicity with a projection optical system onto a predetermined surface, a high contrast is attained while maintaining a

high resolving power, by suitably setting the polarization state of the light beam used for the projection in accordance with the periodicity direction of the pattern, as well as an exposure apparatus using the same. Furthermore, it is an object to provide a method for manufacturing a semiconductor element with a high degree of integration.

[0019]

[Means for Solving the Problem] (1-1) In a first embodiment of the present invention, an imaging method for imaging a line-shaped pattern is characterized in that the pattern is imaged with a polarized light beam that is polarized in a longitudinal direction of that pattern.

[0020] (1-2) In a second embodiment of the present invention, a device manufacturing method in which a line-shaped pattern is imaged onto a workpiece, and a device is manufactured by transferring said pattern onto the workpiece is characterized in that said pattern is imaged with a polarized light beam that is polarized in a longitudinal direction of said pattern.

[0021] (1-3) In a third embodiment of the present invention, an exposure apparatus for exposing a line-shaped pattern onto a substrate is characterized by including means for illuminating said pattern with a polarized light beam that is polarized in a longitudinal direction of said pattern, and means for projecting said pattern illuminated by said illumination means onto said substrate.

[0022] (1-4) In a fourth embodiment of the present invention, an exposure apparatus for exposing a substrate with a line-shaped pattern is characterized by including illumination means for illuminating said pattern with a non-polarized light beam, and projection means for projecting said pattern illuminated by said illumination means onto said substrate with a polarized beam that is polarized in a longitudinal direction of said pattern.

[0023] (1-5) In a fifth embodiment of the present invention, an imaging method for imaging a repeating pattern is characterized in that said pattern is imaged with a polarized light beam that is polarized in a direction substantially perpendicular to the direction in which a repeating period is smallest.

[0024] (1-6) In a sixth embodiment of the present invention, a device manufacturing method in which a repeating pattern is imaged onto a workpiece, and said pattern repeating pattern is transferred onto the workpiece is

characterized in that said pattern is imaged with a polarized light beam that is polarized in a direction substantially perpendicular to the direction in which a repeating period is smallest.

[0025] (1-7) In a seventh embodiment of the present invention, an exposure apparatus for exposing a substrate with a repeating pattern is characterized by including illumination means for illuminating said pattern with a polarized light beam that is polarized in a direction substantially perpendicular to the direction in which the repeating period is smallest, and projection means for projecting said pattern illuminated by said illumination means onto said substrate.

[0026] (1-8) In an eighth embodiment of the present invention, an exposure apparatus for exposing a substrate with a repeating pattern is characterized by including illumination means for illuminating said pattern with a non-polarized light beam and means for projecting said pattern illuminated by said illumination means onto said substrate with a polarized beam that is polarized in a direction substantially perpendicular to the direction in which the repeating period is smallest.

[0027] (1-9) In accordance with the present invention, to illuminate a pattern with a polarized light beam, a polarization plate (film) may be formed on a substrate on which the pattern is formed, a light source emitting polarized light, such as a laser, may be provided, or a polarization plate (film) may be provided within an optical system for this illumination.

[0028] Moreover, in accordance with the present invention, to image the pattern illuminated by the non-polarized light beam with a polarized light beam, a polarization plate (film) may be formed on a substrate, such as a mask, on which the pattern is formed, or a polarization plate (film) may be provided in the optical system for imaging.

[0029] In a preferable embodiment of the present invention, the polarization plate (film) can be rotated around an optical axis of the system, such that the orientation of the polarization plate (film) of the illumination optical system or the imaging optical system can be changed. With this configuration, a polarized beam can be formed that is polarized in the desired direction.

[0030] In another preferable embodiment of the present invention, a 1/2 wavelength plate (film) is provided within said illumination optical system or

imaging optical system, and the 1/2 wavelength plate (film) is configured to be rotatable around the optical axis, so that the orientation of the optical axis of the 1/2 wavelength plate (film) can be changed. With this configuration, a polarized beam can be formed that is polarized in any desired direction.

[0031] Moreover, according to the present invention, when different patterns are formed on the substrate, and the longitudinal directions of these patterns differ from each other, or the directions in which the repeating periods of these patterns are smallest (minimum period direction) differ from each other, then the patterns are imaged with polarized beams corresponding to directions that are perpendicular to the longitudinal directions of the patterns or/and directions perpendicular to the minimum period direction.

[0032] When such imaging is carried out simultaneously, a non-polarized beam may be supplied in a state in which a polarization plate (film) is provided corresponding to each of these patterns, or, in a state in which a 1/2 wavelength plate (film) is provided that generates polarized light corresponding to a pattern or patterns in addition to one pattern, a polarized beam may be supplied that corresponds to said one pattern. The polarization plate (film) or 1/2 wavelength plate (film) should be provided on at least one of the side where the light enters and the side where the light leaves the pattern.

[0033] When sequentially imaging in this manner, the illumination optical system or the imaging optical system is configured as in the above-described preferable embodiment, and polarized light beams corresponding to the patterns are generated.

[0034] In a preferable embodiment of the present invention, the pattern is illuminated from an oblique direction with an illumination beam, or the pattern is provided with a phase shifter, and imaging is performed substantially with two diffraction beams from the pattern.

[0035] (1 – 10) An image projection method according to the present invention is characterized in that:

(1 – 10 – A) a pattern with periodicity is illuminated by a light beam of linearly polarized light corresponding to the direction of periodicity of the pattern, and the pattern is projected by a projection optical system onto a predetermined surface.

[0036] (1 – 10 – B) a pattern with periodicity is illuminated by a light beam of linearly polarized light having a polarization plane that is perpendicular to a direction in which the pattern is arranged, diffraction light from the pattern is incident onto a pupil of a projection optical system, and the pattern is projected onto a predetermined surface.

[0037] (1 – 10 – C) a pattern with periodicity is illuminated, through a polarization device that can change a light beam from an illumination system into linearly polarized light as desired and emit the polarized light beam, by a light beam having a polarization plane that is substantially perpendicular to a direction in which the pattern's period is shortest, diffraction light from the pattern is incident onto a pupil of a projection optical system, and the pattern is projected onto a predetermined surface.

[0038] (1 – 10 – D) a pattern with periodicity is illuminated, and when projecting the pattern onto a predetermined surface with a projection optical system, it is projected with a linearly polarized light beam corresponding to a direction of periodicity of the pattern.

[0039] (1 – 10 – E) a pattern with periodicity is illuminated, and when the pattern is projected onto a predetermined surface by causing diffraction light from the pattern to be incident on a pupil of the projection optical system, it is projected with a linearly polarized light beam having a polarization plane in a direction perpendicular to a direction in which the pattern is arranged.

[0040] (1 – 10 – F) a pattern with periodicity is illuminated with a light beam from an illumination system, and when the pattern is projected onto a predetermined surface by causing diffraction light from the pattern to be incident on a pupil of the projection optical system, the projection of the pattern is performed by selecting, with a polarization device, a light beam having a polarization plane in a direction that is substantially perpendicular to a direction in which the period of the pattern is shortest.

[0041] (1 – 11) An exposure apparatus according to the present invention is characterized in that:

(1 – 11 – A) a pattern with periodicity on a reticle surface is illuminated with a light beam from an illumination system, and when an image of the pattern is projected onto a wafer surface by causing diffraction light from the pattern to be

incident on a pupil of a projection optical system, the pattern is illuminated with a light beam of linearly polarized light having a polarization plane that is substantially perpendicular to the direction in which the period of the pattern is shortest.

[0042] (1 – 11 – B) a pattern with periodicity on a reticle surface is illuminated with a light beam from an illumination system, and when an image of the pattern is projected onto a wafer surface by causing diffraction light from the pattern to be incident on a pupil of a projection optical system, it is projected by selecting, with a polarization device, a linearly polarized light beam having a polarization plane in a direction that is substantially perpendicular to a direction in which the period of the pattern is shortest.

[0043]

[Working Examples] First, before explaining working examples of the present invention, the so-called scalar diffraction theory used for ordinary simulation of imaging characteristics as well as an even more precise theory than this scalar diffraction theory used for the simulation by the present invention are explained.

[0044] In scalar diffraction theory, when a physical pattern is illuminated, the Fourier transform image of this pattern is formed on the entry pupil of the projection optical system, and again Fourier-converting this Fourier transform image within a range of the numerical aperture (NA) of the projection optical system, a pattern image with a certain amplitude distribution is formed on the image plane. Expressing this in an equation, the amplitude A(x, y) at the point (x, y) on the image plane can be written as:

[0045]

[Eq. 1]

$$A(x, y) = \iint F\left(U(x_1, y_1)\right) \exp\left\{ik(\alpha x + \beta y)\right\} d\alpha\, d\beta$$

The term $F(U(x_1, y_1))$ in this equation is the Fourier transform of the amplitude transmittance $U(x_1, y_1)$ of the pattern, and this Fourier transform is again Fourier transformed within the range of the pupil plane, which is determined by

the numerical aperture of the projection optical system. Note that (α, β) in this equation are the coordinates on the pupil plane, and $F(U(x_1, y_1))$ is a function of (α, β).

[0046] This equation is for the case that the illumination light is coherent, and also for the case that the illumination light is partially coherent, it is substantially the same, although its handling becomes somewhat difficult.

[0047] In a simulation using the above-noted equation, the correct result is attained if the numerical aperture of the projection optical system is small, but studies by the inventors have shown that when the numerical aperture becomes large, various problems occur.

[0048] The largest problem with the above-noted equation is that it does not consider the polarization state of the incident light. This shall be explained with reference to the drawings. In the explanations, the example of the repeating pattern of three slits noted above is used.

[0049] Fig. 26 shows the amplitude distribution on the pupil shown in Fig. 33 rendered on a reference sphere 111 centered on a Gauss image point 110 of the projection optical system. Ignoring the wavefront aberrations of the projection optical system, the amplitude at the point 110 on the image plane 112 is determined by integrating the amplitude on the reference sphere 111, or, the amplitude at a point that is shifted by the distance x from the point 110 on the image plane 112 is calculated by integrating the amplitude on the reference sphere 111, giving consideration to a certain phase shift, which is determined from the distance x and the coordinates on the reference sphere 111.

[0050] In order to keep things simple, the following discussion is limited to the calculation of the amplitude at the point 110. Moreover, a definition of the coordination axes shall be given here.

[0051] As shown in Fig. 26, the optical axis is the z-axis, the axis perpendicular to the z-axis in the paper plane is the x-axis, and the axis perpendicular to the paper plane is the y-axis. According to the above-noted scalar diffraction theory, the amplitude at the point 110 is calculated by simply adding up the amplitudes on the reference sphere 111.

[0052] Light is subject to polarization, and when for example the polarization directions of completely coherent light beams are different, then there is only

partial interference, and when they are for example orthogonal to each other, then there is no interference at all.

[0053] When the longitudinal direction of the slits constituting a repeating pattern is parallel to the y-axis, the repeating pattern is periodic in the direction of the x-axis, and the slits are illuminated with light from a direction parallel to the z-axis, then the amplitude distribution of Fig. 26 is formed on the reference sphere 111. If the illumination light is linearly polarized light that is polarized in the y-axis direction (the direction parallel to the slits), then, ignoring changes in the polarization direction within the projection optical system, also the polarization direction at each point of the amplitude distribution will be the y-axis direction for all positions, as in the illumination light.

[0054] When the amplitude distribution on the reference sphere 111 is formed only by light that is polarized in the y-axis direction, out of the light that is diffracted by the slits, then also the polarization directions of the light that reaches the image plane 112 will all be identical. Also in this case, the amplitude at the point 110 is determined by simply integrating the amplitude on the reference sphere 111.

[0055] On the other hand, if the illumination light is linearly polarized light that is polarized in the x-axis direction (a direction perpendicular to the slits), then, as shown in Fig. 27, the polarization directions of the representative light rays 120 to 124 travelling from the reference sphere 111 to the point 110 become as indicated by the arrows 125 to 129 in the drawing, under the condition that the polarization direction and the propagation direction of the light are perpendicular to each other. In this case, the polarized light has both x- and z-polarized components, and the amplitude at the point 110 must be considered for both polarization components individually. The intensity of the light at the point 110 is the sum of the intensities obtained from the amplitudes due to the respective polarization components.

[0056] The following is an explanation of the results of performing a simulation applying these ideas. First of all, Figs. 28 and 29 show the resulting intensity distributions that are obtained for the two polarization directions of the illumination light, that is, using the polarization component of either the x-axis direction or the y-axis direction of the light diffracted at the slits, when imaging

using the 0-order, +1st-order and -1st-order diffraction light components explained with Fig. 33.

[0057] Fig. 28 shows the case that the polarization direction of the illumination light is parallel to the slits, so that the image is formed only by the polarization components in y-axis direction. By contrast, Fig. 29 shows the case that the polarization direction of the illumination light is perpendicular to the slits, so that the image is formed by the sum of the x-polarized components and the z-polarized components.

[0058] The following is a discussion of the results of a similar simulation, in which imaging was performed using two out of the three diffraction lights of 0-order, +1st-order and -1st-order diffraction light, as in the phase shift method and the oblique incidence illumination method.

[0059] When only the result of the intensity distribution on the image plane is shown, then the intensity distribution for the case that the polarization direction of the illumination is the y-axis direction (parallel to the slits) becomes as shown in Fig. 30, and the intensity distribution for the case that the polarization direction of the illumination is the x-axis direction (perpendicular to the slits) becomes as shown in Fig. 31.

[0060] Here, due to the influence of the polarization components in the z-direction, the contrast of the image is much poorer in the case that the polarization direction is perpendicular to the slits than in the case that the polarization direction is parallel to the slits. In an ordinary exposure, the illumination light is not polarized, so that the intensity distribution is an average of that in the Figs. 30 and 31, in which case the contrast is further deteriorated in comparison to the intensity distribution of Fig. 31.

[0061] Thus, it became clear from the result of a highly precise simulation performed by the inventors that the polarization direction of the illumination light exerts a large influence on the imaging characteristics.

[0062] In particular, if the phase shift method or the oblique incidence illumination method is applied in order to increase the resolution, a resolution that exceeds expectations is attained by suitably controlling the polarization direction of the illumination light for projected patterns with periodicity.

[0063] This concludes the explanation of the results of our simulation relating to the imaging characteristics performed by the present inventors.

[0064] The following is an explanation of working examples of the present invention.

[0065] Fig. 1 is a diagrammatic view of the main parts of Working Example 1, in which an image projection method according to the present invention is applied to a stepper (step-and-repeat projection exposure apparatus) for manufacturing such devices as semiconductor elements, CCDs, liquid crystal panels or magnetic heads.

[0066] In the drawings, numeral 1 denotes a light source, such as a super-high pressure mercury lamp. The light amount distribution of the light emanating from the light source 1 is equalized by an optical integrator 2, and a pattern (circuit pattern) 4a on a reticle 4 is illuminated by an illumination lens 3, through an aperture 8 and a polarization device 9. The light diffracted at the pattern 4a of the reticle 4 enters a projection lens 5, and, having passed through the projection lens 5, forms an image of the pattern 4a on a semiconductor wafer 6 placed on a stage 7.

[0067] Here, not all light beams of the light emitted from the optical integrator 2 reach the illumination lens 3, and when only a portion that is suitable for illumination is selected by the aperture 8 at a location serving as an aperture stop that is placed close to the optical integrator 2 and the selected light passes through the polarization device 9, then the polarization state is converted from circular or elliptical polarization into linear polarization. The polarization device 9 can change the polarization direction of the linearly polarized light in accordance with conditions such as the repeating direction of the pattern 4a.

[0068] A circuit pattern 4a with small line width for transfer onto the barrel[1] wafer 6 is drawn onto the reticle 4, and the illumination light incident through the illumination lens 3 on the reticle 4 passes through the reticle 4 in accordance with this circuit pattern 4a. A photosensitive material, such as a resist, is applied to the semiconductor wafer 6, and it is possible to transfer an image of the circuit pattern 4a to it.

---

[1] Translator's note: Possibly a typo for „semiconductor"

[0069] The projection lens 5 projects the image of the circuit pattern 4a on the reticle 4 onto the semiconductor wafer 6 at a reduction by a predetermined ratio (ordinarily, 1/5 or 1/10). For this, the reticle 4 and the semiconductor wafer 6 are adjusted to a predetermined positional relation by driving the stage 7. When the exposure of a certain shot on the semiconductor wafer 6 has finished, the semiconductor wafer 6 is moved by a predetermined amount in horizontal direction by the stage 7, and thus, the exposure of other shots on the semiconductor wafer 6 is repeated.

[0070] In the present working example, a repeating pattern with periodicity in the x-direction is used, in which five slits extending in y-direction are lined up in x-direction as shown in Fig. 2 as the circuit pattern 4a on the reticle 4. Numerals 10 to 14 in the drawing are openings, the surroundings of these openings 10 to 14 being made of a light-blocking portion, and the light passes only through these portions. The dash-dotted line 15, which will be used for the later explanations, is a reference line drawn in the repeating direction of the slit-shaped openings 10 to 14 (x-direction).

[0071] Here, the reticle 4 is illuminated with light beams whose main light ray is tilted with respect to a direction perpendicular to the reticle 4, thereby improving the contrast of the image.

[0072] Fig. 3 is a cross-sectional view taken along the dash-dotted line 15 of the pattern 4a in Fig. 2. The direction in which the light beams 20 and 21 are tilted with the oblique incidence illumination method is set such that the main light rays of the light beams are oblique within the ZX-plane, in which the pattern 4a is repeated, as shown in Fig. 3. In order to satisfy this condition, the openings for the aperture 8 in the present embodiment are configured as shown in Fig. 4. Note that the x-axis points in a direction in which the repeating period of the pattern 4a is smallest.

[0073] In Fig. 4, the hatched portion 22 denotes a light-blocking region, which blocks light such that no light can pass through it. The two circular openings 23 and 24 are light-passing regions, and the light from these regions 23, 24 contributes to the imaging of the pattern 4a. In the drawing, numeral 25 denotes a reference line that is drawn such that it passes through the center of the circular openings 23 and 24.

[0074] The illumination light selected by the aperture 8 of Fig. 1 is incident next on the polarization device 9. As shown in Fig. 5, the polarization device 9 is configured such that, of the polarized light components of the light incident on the upper surface of the polarization device 9, it passes only light polarized in the y-direction, indicated by arrows 26 in the drawings, and blocks light polarized in any other direction. The dash-dotted line 27 is a reference line that is drawn in a direction perpendicular to the above-noted arrows 26. The arrangement within the horizontal plane of the reticle 4, the aperture 8 and the polarization device 9 in Fig. 1 is such that the reference lines 15, 25 and 27 shown respectively in the Figs. 2, 4 and 5 are parallel to each other.

[0075] With the above-described configuration, the polarization direction of the obliquely incident illumination light is set to the y-direction, which is parallel to the direction of the slits of the pattern 4a, that is, perpendicular to the x-direction, in which the repeating period of the pattern 4a is smallest, so that by imaging and imprinting the pattern 4a, an image with high resolution and high contrast, as explained with Fig. 30, is obtained on the semiconductor wafer 6. The same effect is also attained in the case that the pattern on the reticle 4 is a dot-shaped repeating pattern.

[0076] Next, a case is explained that in the present working example, the pattern 4a on the reticle 4 is not only a single pattern with periodicity in one direction, as in Fig. 2, but two patterns with periodicity in two directions, namely in height and lateral direction (y, x), as shown in Fig. 6.

[0077] In this case, the repeating pattern of the portion enclosed by the broken line 30 in Fig. 6 can be favourably projected and transferred by using the above-described method. However, for the repeating pattern of the portion enclosed by the broken line 31, the polarization direction of the illumination light is perpendicular to the slits, so that the same effect cannot be attained.

[0078] Accordingly, in the present working example, the reticle in Fig. 6 is separated into two reticles, as shown in Figs. 7 and 8, which are exposed separately. That is to say, as explained above, the pattern in Fig. 7 is imprinted with linearly polarized light that is polarized in the y-direction, and the pattern in Fig. 8 is imprinted after rotating the aperture 8 and the polarization device 9 with a driving device (not shown in the drawings) by 90° in the horizontal plane

around the optical axis and fixing them, such that the polarization direction of the illumination light is parallel to the longitudinal direction of the slits, that is, it becomes linearly polarized light that is polarized in the x-direction. In this method, the pattern of the slits is not limited to the two height and lateral directions, and may be similarly applied to other directions as well.

[0079] Moreover, if there are two repeating patterns on one reticle, as shown in Fig. 6, the patterns may be illuminated sequentially using a masking blade that is provided at a location that is conjugate to the reticle, illuminating the patterns with the above-described method with polarized light.

[0080] In the present working example, it was explained that the pattern on the reticle is formed with five lines and spaces, but it can be similarly applied to patterns other than those of five lines and spaces. Moreover, there is no limitation to a width ratio of 1:1 for the lines and spaces, and furthermore, the present invention can be similarly applied also to cases in which the period of the pattern is somewhat irregular.

[0081] Moreover, in the present working example, the polarization device 9 may also be arranged between the illumination lens 3 and the reticle 4, or between the reticle 4 and the projection lens 5, or within the projection lens 5 (above the pupil plane).

[0082] If the polarization device 9 is arranged between the reticle 4 and the projection lens 5, then polarized light that is polarized by the polarization device 9 in a specific direction is selected out of the diffraction light diffracted by the pattern 4a in accordance with the pattern shape on the reticle 4, and only the selected polarized light beams are incident on the projection lens 5. The image of the pattern 4a is then projected with these polarized light beams onto the wafer 6.

[0083] The following is an explanation of the Working Example 2 of the present invention. The device configuration of the Working Example 2 is substantially the same as that of Working Example 1 in Fig. 1. The aspect where Working Example 2 differs from Working Example 1 is that the phase shift method is applied to the pattern on the reticle 4.

[0084] Fig. 9 is a diagram illustrating the pattern 4a on the reticle 4 of the present working example. As shown in this diagram, the aspect that the pattern 4a is made of five slit-shaped openings 40 to 44 extending in the y-direction is the

same as in Working Example 1 in Fig. 1, but the pattern in Fig. 9 is characterized in that phase shifters are provided that change the phase of the light passing through the hatched portions 40, 42, and 44 by 180° with respect to the light passing through the portions 41 and 43.

[0085] Moreover, in the present working example, the aperture 8 is provided with a shape with which light can pass only through an opening of a circular portion 46 at the center that is surrounded by the light-blocking portion of a hatched portion 45, as shown in Fig. 10.

[0086] In the present working example, the pattern 4a and the aperture 8 are combined with the same polarization device 9 as in Working Example 1, and with the pattern 4a in Fig. 9, the polarization direction of the illumination light is arranged to be parallel to the longitudinal direction of the slits (y-direction). Thus, a favourable pattern is imprinted with the phase shift method.

[0087] Moreover, also when the pattern 4a on the reticle 4 is not of one type as in Fig. 9, but of different types repeating in different directions as in Fig. 6, the working example can be applied by using a plurality of reticles, one each for the patterns with the same orientation, as in Working Example 1, or using a masking blade to partition and imprint.

[0088] Next, a Working Example 3 of the present invention is explained. Also the device configuration of Working Example 3 is substantially the same as that of Working Example 1 in Fig. 1.

[0089] In the present working example, the pattern shown in Fig. 11 is used as a pattern 4a on the reticle 4. In Fig. 11, numeral 4 denotes the reticle, and the coordinate system is defined such that the reticle 4 is arranged parallel to the xy-plane and the z-axis is perpendicular to the reticle 4, as in the other working examples. In Fig. 11, the numerals 210 to 214 denote slit-shape opening portions of the pattern A, constituting a repeating pattern in the x-direction indicated by arrow 215.

[0090] Similarly, the numerals 220 to 224 denote slit-shape opening portions of the pattern B, constituting a repeating pattern in the y-direction indicated by arrow 225. The phase shift method is applied to each of the patterns A and B. The patterns A and B to which the phase shift method is applied are explained in detail with reference to Fig. 12.

[0091] Fig. 12 is a cross-sectional view of pattern A shown in Fig. 11, taken along arrow 215. In Fig. 12, numeral 230 denotes a transparent glass plate, and the hatched portion 231 denotes a light-blocking portion made of chrome. The periodic pattern A is formed by the light-blocking portion 231 and the opening portions 210 to 214. The phase shift method improves the resolution of the imaging system by changing the phase of the light passing through the aperture portions by 180° between neighboring aperture portions. Numerals 32 to 34 in Fig. 12 indicate phase shifters that change the phase of the light passing therethrough by 180°.

[0092] Also with respect to the periodic pattern B, the cross-sectional view along the arrow 225 is the same as in Fig. 12. To image the pattern under application of the phase shift method, illumination should be carried out from a direction perpendicular to the reticle 4 (z-direction), so that as the aperture 8, as shown in Fig. 13, an aperture is used in which the hatched portion 240 at the periphery is a light-blocking portion, and an opening 241 is provided at the center.

[0093] In the present working example, a polarization device 9 as shown in Fig. 14 is applied. The polarization device 9 is configured such that, of the light incident on it, only light polarized in the y-direction indicated by the double-sided arrows 50 in Fig. 14 passes therethrough. That is to say, the illumination light of the stepper according to the present working example is linearly polarized light that, after having passed through the polarization device 9, has a polarization plane including the y-direction.

[0094] When the pattern 4a of the reticle 4 is illuminated with the above-described configuration, the relation between the patterns A and B and the polarization direction of the illumination light becomes as shown in Figs. 15 and 16. That is to say, as shown in Fig. 15, the polarization direction 60 is parallel to the longitudinal direction of the slits constituting pattern A, satisfying the conditions for improving the resolution, as explained previously.

[0095] On the other hand, as shown in Fig. 16, the polarization direction 61 is perpendicular to the longitudinal direction of the slits constituting pattern B, so that for pattern B, the resolution cannot be improved as much as for pattern A.

[0096] Accordingly, the present working example is arranged such that the polarization plane of the linearly polarized light beam incident on the pattern B

is rotated by 90°, and the pattern B can be illuminated with a linearly polarized light beam of a direction parallel to the slits of the pattern B.

[0097] Like Fig. 11, Fig. 17 is a planar view of a reticle 4 with a pattern A and a pattern B, but the reticle 4 of Fig. 17 is characterized in that a polarization converting device 70 that rotates the polarization plane of the incident linearly polarized light beam by 90° is polarized[2] immediately before the pattern B. For the polarization converting device 70, a 1/2 wavelength plate can be employed, for example. Using Fig. 24 [sic], the following is an explanation of how the polarization plane is rotated when a 1/2 wavelength plate is employed.

[0098] In case of a linearly polarized light beam advancing in the direction of arrow 80 and polarized in the direction of double-arrow 81 (y-direction) in Fig. 18, when the direction of the optical axis 82 of the polarization converting device (here: 1/2 wavelength plate) is arranged such that it forms an angle of 45° with the x-axis, a light beam that has passed through the polarization converting device 70 advances in the direction of the arrow 83, and is converted into a linearly polarized light beam that is polarized in the x-axis direction, as indicated by the double-arrow 84.

[0099] By arranging the polarization converting device 70 immediately before the pattern B, the relation between pattern B and the polarization direction of the illumination light beam becomes as shown in Fig. 19. That is to say, the direction of the polarization as indicated by the double-arrow 90 becomes parallel to the slits constituting the pattern B, so that also for pattern B the resolution can be improved, like for pattern A.

[0100] If an optically active material is employed as the polarization converting device 70, then it is possible to control the amount of the rotation of the polarization plane of the linearly polarized light only with the thickness of the polarization converting device 70, and in this case, the rotation angle of the polarization plane of the linearly polarized light can be set to a value other than 90° by controlling the thickness, so that it is possible to improve the resolution for repeating patterns of various directions.

[0101] The present working example was explained for the case that the phase shift method is applied to the pattern to be illuminated, but needless to say, it

[2] Translator's note: Possibly a typo for „is arranged".

can also be applied in cases where the oblique incidence illumination method is used.

[0102] In modified examples of the foregoing working examples, the polarization device 9 is formed on the front surface or rear surface of the reticle 1.

[0103] Fig. 20 is a diagrammatic view of the main parts of Working Example 4, in which an image projection method of the present invention is applied to a stepper for manufacturing a semiconductor element. In this drawing, elements that are the same as elements shown in Fig. 1 are given the same reference numerals.

[0104] In Fig. 20, the light source 1, the optical integrator 2, the illumination lens 3, the reticle 4, the projection lens 5, the semiconductor wafer 6, the stage 7 and so on are similar to those in Fig. 1, so that further explanations thereof are omitted.

[0105] The aspect where Working Example 4 differs from Working Examples 1 to 3 is the position where the polarization device is arranged in the light path. In the present working example, a polarization device 59 is arranged immediately before the reticle 54 (between the illumination lens 3 and the reticle 54), and is adapted to control the polarization state of the light entering the reticle 54 immediately before the reticle 54.

[0106] Here, the pattern 54a on the reticle 54 of the present working example is made of a repeating pattern made of slits 60 to 64 extending in height direction (y-direction) and a repeating pattern made of slits 65 to 69 extending in lateral direction (x-direction), as shown in Fig. 21. Thus, to increase the resolution by oblique illumination on the patterns in height and lateral direction, the opening of the aperture 8 should be as in Fig. 22.

[0107] The hatched portion 70 in Fig. 22 is a light-blocking portion, whereas the circular opening portions 71 to 74 arranged at the four corners of a square are light-passing portions. The light from the opening portions 71 to 74 is obliquely incident on the reticle 4.

[0108] In the present working example, with this oblique incidence illumination method, the polarization device 59 is arranged such that the polarization direction of the light that is incident on the pattern 54a is always parallel to the longitudinal direction of the slits.

[0109] Numerals 59a and 59b in Fig. 21 denote polarization members that pass, of the light incident on them, only linearly polarized light that is polarized in one direction. The polarization member 59a is set such that it passes, of the light incident on it, only polarized light that is polarized in a direction parallel to the longitudinal direction of the slits 60 to 64 (y-direction).

[0110] On the other hand, the polarization member 59b is set such that it passes only polarized light that is polarized in a direction parallel to the longitudinal direction of the slits 65 to 69 (x-direction). It is possible to employ a polarization device 59, in which several thin film-shaped polarization plates are attached to the reticle 54 in accordance with the patterns corresponding to their respective polarization axis direction, for example.

[0111] The present working example was explained for the case that slits extending in height direction and in lateral direction are provided as the pattern 54a on the reticle 54, but it can be similarly applied also to patterns having slits extending in other directions.

[0112] It should be noted that in the present working example, the polarization device 9 may also be arranged immediately after the reticle 54 (between the reticle 54 and the projection lens 55).

[0113] In this case, when there are slits extending in several directions on the reticle 54, the polarization device 9 is configured such that it can select, of the light diffracted from the slits, polarized light that is polarized in the longitudinal direction of the slits, independently for the respective directions of the slits, and perform imaging with this polarized light.

[0114] The following is an explanation of Working Example 5 of the working examples. The apparatus configuration of Working Example 5 is substantially the same as that of Working Example 1 in Fig. 1. Where Working Example 5 differs from Working Example 4 is that the phase shift method is applied to the pattern on the reticle 4.

[0115] Fig. 23 is a diagrammatic view of a pattern 54a on the surface of a reticle 54 of the present working example. The pattern on the reticle 54 shown in this figure is similar to the pattern of Fig. 21 in that it is constituted by slits 80 to 84 extending in height direction (y-direction) and slits 85 to 89 extending in lateral direction (x-direction) on the reticle 54 shown in the figure, but the present

working example differs with regard to the fact that in the portions 80, 82, 84, 85, 87 and 89 in which the slits in the figures are provided with hatching, a phase shift member is provided that changes the phase of the light passing therethrough by 180° with respect to the light passing through the portions 81, 83, 86 and 88.

[0116] Numerals 59a and 59b are polarization members, and if circularly or elliptically polarized light or non-polarized light is incident on the reticle 54, only the polarized light that is polarized in the longitudinal direction of the slits is incident on the slits. Moreover, as in the case of Working Example 2, an aperture 8 as shown in Fig. 13 is used.

[0117] In the present working example, with the above-described configuration, the resolution is improved with the phase shift method and even when there are patterns in the height and the lateral directions on the reticle 54, the imaging on the semiconductor wafer 6 is performed with polarized light that is suitable for each pattern.

[0118] Here, a working example was explained that slits extending on two directions, height and lateral direction, are provided as the patterns on the reticle 54, but it is also possible to apply this working example to patterns having slits extending in other directions.

[0119] Here, an example was shown in which the pattern on the reticle is formed with five lines and spaces, but this example can be applied similarly to patterns other than five lines and spaces. Also, the example may be applied similarly to cases in which the width ratio of the lines and spaces is not limited to 1:1, or the periodicity of the pattern is to a certain extent irregular.

[0120] Moreover, instead of using a lamp and a polarization device, it is also possible to use a laser emitting linearly polarized light as the light source for the exposure light. When a polarization device is used, or a laser is used, it is possible to insert a 1/2 wavelength plate into the light path and to produce light of the desired polarization by rotating the same.

[0121] The following is an explanation of a working example of a device manufacturing method using the above-described exposure apparatus. Fig. 24 shows a flowchart of the manufacture of a semiconductor element (a

semiconductor chip, such as an IC or an LSI, a liquid crystal panel, a CCD or the like).

[0122] In Step 1 (circuit design), the circuit design of the semiconductor element is carried out. In Step 2 (mask fabrication), a mask is fabricated on which the designed circuit pattern is formed.

[0123] On the other hand, in Step 3 (wafer manufacture), a wafer is manufactured using a material such as silicon. In Step 4 (wafer processing), in what is called pre-processing, a circuit of a working example is formed on the wafer by lithography using the mask and wafer prepared as above.

[0124] The next Step 5 (assembly), which is called after-processing, is a step of making semiconductor chips using the wafer fabricated in Step 4, and includes such steps as an assembly step (dicing, bonding), and a packaging step (chip sealing). In Step 6 (inspection), inspections such as an operation confirmation test and a durability test of the semiconductor element fabricated in Step 5 are carried out, for example. Through these steps, the semiconductor element is finished and shipped (Step 7).

[0125] Fig. 25 shows a detailed flowchart of the above-mentioned wafer processing.

[0126] In Step 11 (oxidation), the surface of the wafer is oxidized. In Step 12 (CVD), an isolating film is formed on the wafer surface. In Step 13 (electrode formation), an electrode is formed on the wafer by vapor deposition. In Step 14 (ion implantation), ions are implanted into the wafer. In Step 15 (resist processing), the wafer is coated with a photosensitive agent. In Step 16 (exposure), the circuit pattern of the mask is exposed onto the wafer with the exposure apparatus explained above. In Step 17 (development), the exposed wafer is developed. In Step 18 (etching), the parts other than the developed resist imaged are removed. In Step 19 (resist stripping), the resist that has been etched and become unnecessary is removed. By repeating these steps, a circuit pattern is formed with multiple layers on the wafer.

[0127] Using the manufacturing method of this working example, it is possible to manufacture a semiconductor element with a high integration, which was conventionally difficult to manufacture.

[0128]

[Effect of the Invention] With the present invention, by setting the various elements as described above, it is possible to achieve an improved imaging method, an exposure apparatus using this method, and method for manufacturing a device using this method, that are suitable for imaging microscopic patterns.

[0129] Furthermore, with the present invention, when projecting a pattern with periodicity with a projection optical system onto a predetermined surface as described above, it is possible to attain an image projecting method, an exposure apparatus and a manufacturing method suitable for manufacturing a semiconductor element that can project with high contrast while maintaining a high resolving power, by suitably setting the polarization state of a light beam used for the projection, in accordance with a periodicity direction of the pattern.

[Brief Description of the Drawings]

[Fig. 1] Diagrammatic view of the main parts of Working Example 1, in which an image projection method according to the present invention is applied to a stepper,

[Fig. 2] Diagrammatic view of reticle in Fig. 1,

[Fig. 3] Diagrammatic view illustrating how the reticle in Fig. 1 is illuminated,

[Fig. 4] Diagrammatic view of the aperture in Fig. 1,

[Fig. 5] Diagrammatic view of the polarization device in Fig. 1,

[Fig. 6] Diagrammatic view of another working example of the reticle in Fig. 1,

[Fig. 7] Diagrammatic view of a portion of Fig. 6,

[Fig. 8] Diagrammatic view of a portion of Fig. 6,

[Fig. 9] Diagrammatic view of a reticle according to Working Example 2 of the present invention,

[Fig. 10] Diagrammatic view of an aperture according to Working Example 2 of the present invention,

[Fig. 11] Diagram showing the pattern on a reticle,

[Fig. 12] Diagram showing a cross section through the pattern on the reticle in Fig. 11,

[Fig. 13] Diagram showing an aperture according to Working Example 3 of the present invention,

[Fig. 14] Diagram showing a polarization device according to Working Example 3 of the present invention,

[Fig. 15] Diagram showing the relation between the pattern in Fig. 11 and the polarization of the illumination light,

[Fig. 16] Diagram showing the relation between the pattern in Fig. 11 and the polarization of the illumination light,

[Fig. 17] Diagram showing the pattern on the reticle according to Working Example 3 of the present invention,

[Fig. 18] Diagram showing the function of the polarization changing device according to Working Example 3 of the present invention,

[Fig. 19] Diagram showing the relation between the pattern in Fig. 17 and the polarization of the illumination light,

[Fig. 20] Diagrammatic view of the main parts of Working Example 4, in which an image projection method of the present invention is applied to a stepper,

[Fig. 21] Diagrammatic view of a portion of Fig. 11,

[Fig. 22] Diagrammatic view of a portion of Fig. 11,

[Fig. 23] Diagrammatic view of a reticle according to Working Example 5 of the present invention,

[Fig. 24] Flowchart of a method for manufacturing a semiconductor element according to the present invention,

[Fig. 25] Flowchart of the wafer processing in the method for manufacturing a semiconductor element according to the present invention,

[Fig. 26] Diagrammatic view showing the amplitude distribution on the pupil,

[Fig. 27] Diagrammatic view illustrating the differences in the polarization directions depending on the angle of the light ray,

[Fig. 28] Diagrammatic view illustrating the intensity distribution on the image plane when using light that is polarized in a direction parallel to the slits,

[Fig. 29] Diagrammatic view illustrating the intensity distribution on the image plane when using light that is polarized in a direction perpendicular to the slits,

[Fig. 30] Diagrammatic view illustrating the intensity distribution on the image plane with the phase shift method or oblique incidence illumination when using light that is polarized in a direction parallel to the slits,

[Fig. 31] Diagrammatic view illustrating the intensity distribution on the image plane with the phase shift method or oblique incidence illumination when using light that is polarized in a direction perpendicular to the slits,

[Fig. 32] Diagrammatic view showing the amplitude transmittance of a repeating pattern,

[Fig. 33] Diagrammatic view showing the amplitude distribution on the pupil,

[Fig. 34] Diagrammatic view showing the intensity distribution on the image plane,

[Fig. 35] Diagrammatic view showing the amplitude distribution on the pupil when using the phase shift method,

[Fig. 36] Diagrammatic view showing the amplitude distribution on the pupil when using the oblique incidence illumination method.

[Index to the Reference Numerals]

1 light source
2 optical integrator
3 illumination lens
4 reticle
5 projection lens
6 semiconductor wafer
7 stage
8 aperture
9 polarization device

* * *

Fig. 1

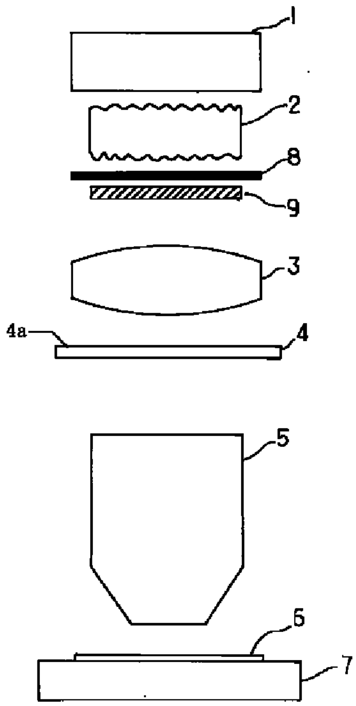


Fig. 2

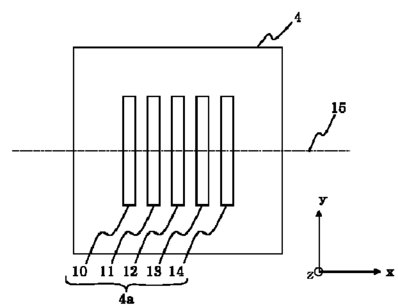


Fig. 3

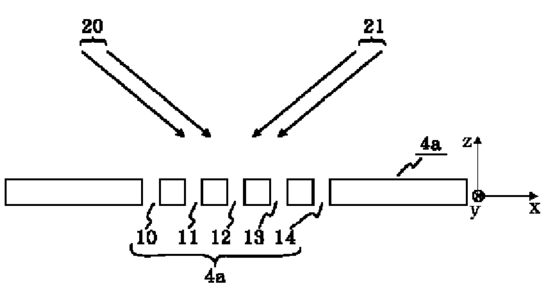


Fig. 4

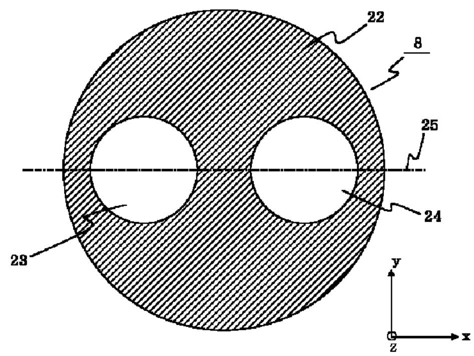


Fig. 5

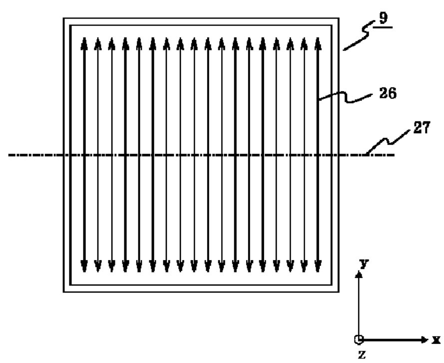


Fig. 6

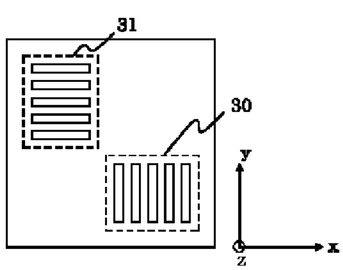


Fig. 7

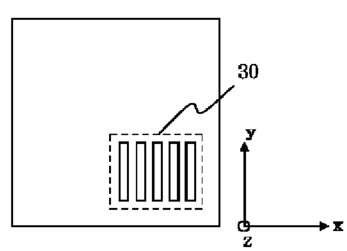


Fig. 8

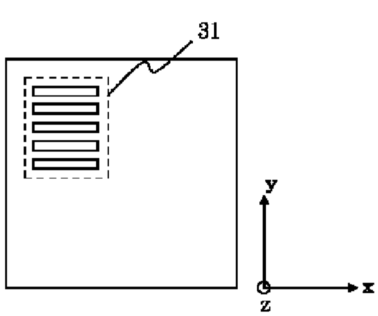


Fig. 9

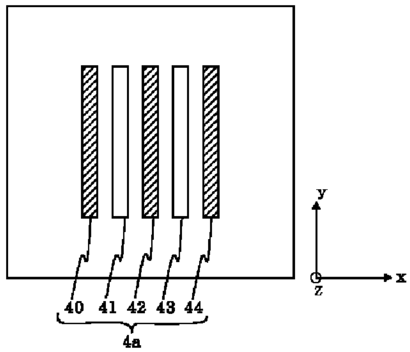


Fig. 10

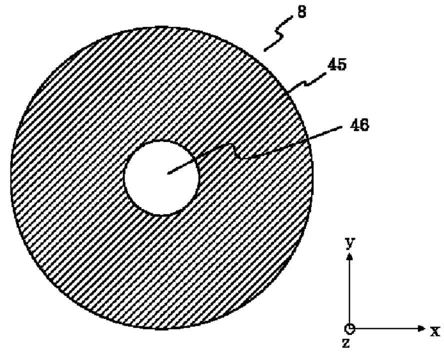


Fig. 11

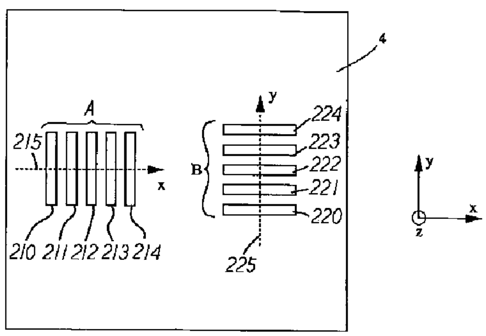


Fig. 12

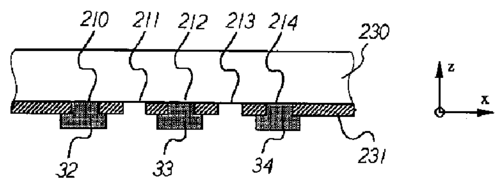


Fig. 13

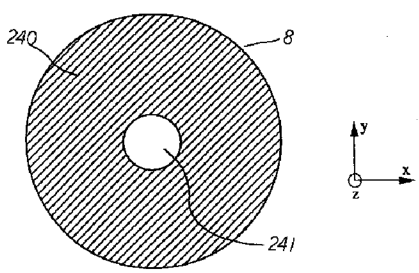


Fig. 14

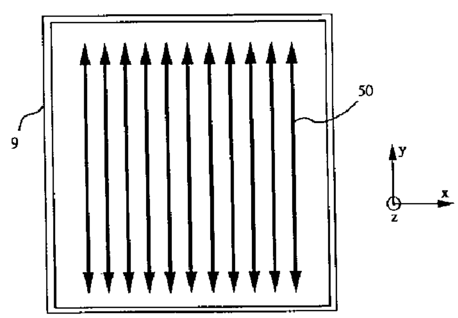


Fig. 15

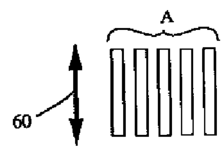


Fig. 16

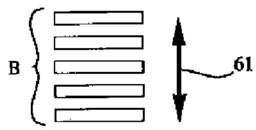


Fig. 17

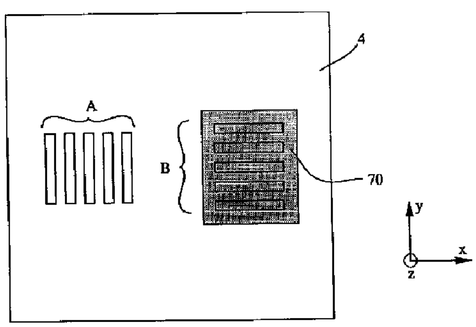


Fig. 18

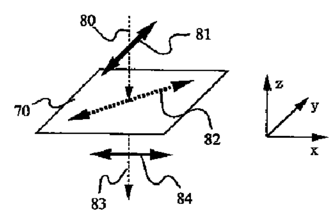


Fig. 19

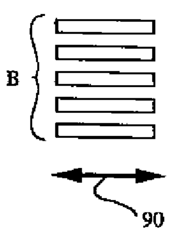


Fig. 20

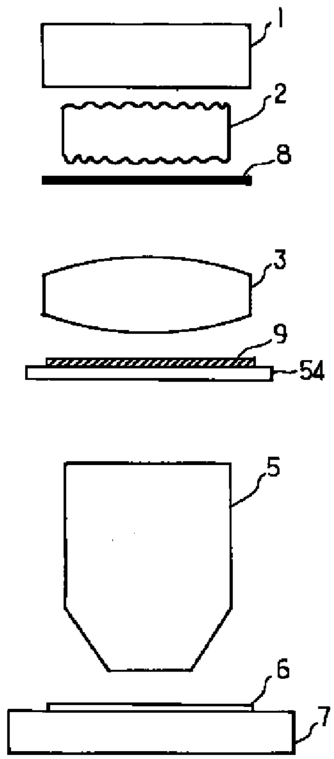


Fig. 21

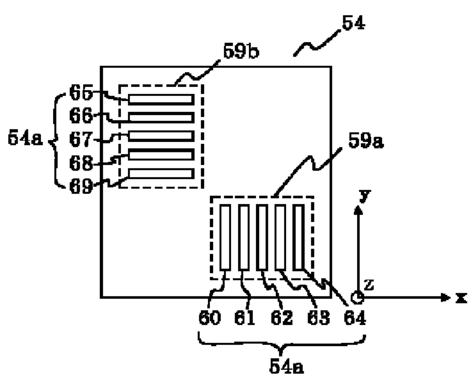


Fig. 22

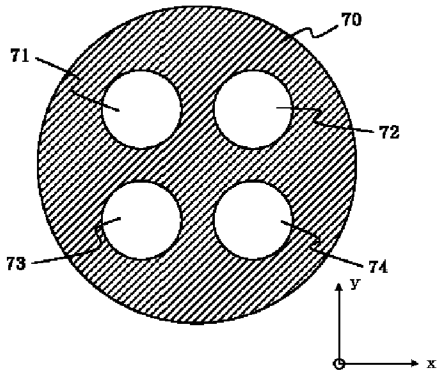


Fig. 23

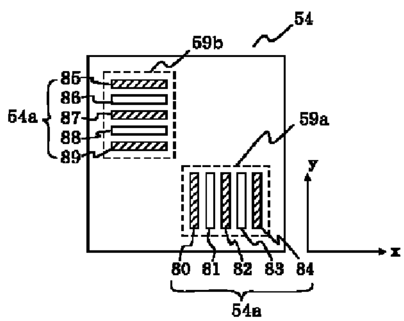


Fig. 24

Semiconductor Device Manufacturing Flow

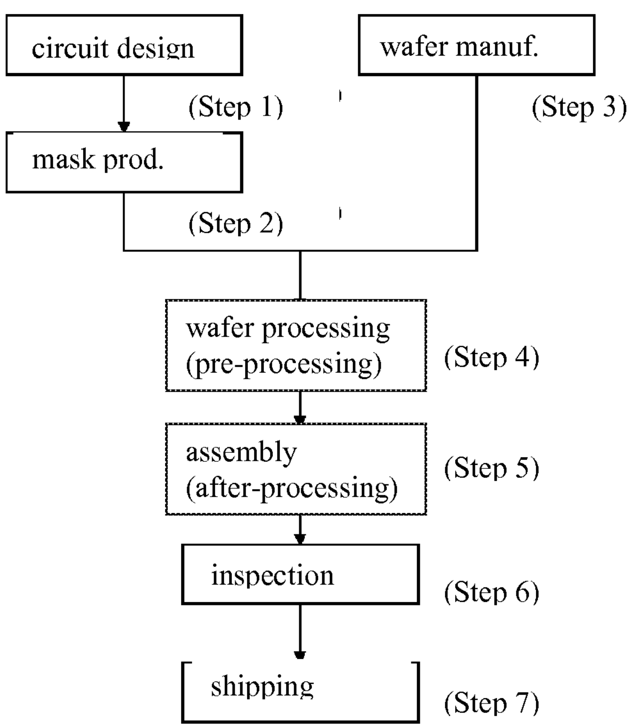


Fig. 25

Wafer Processing

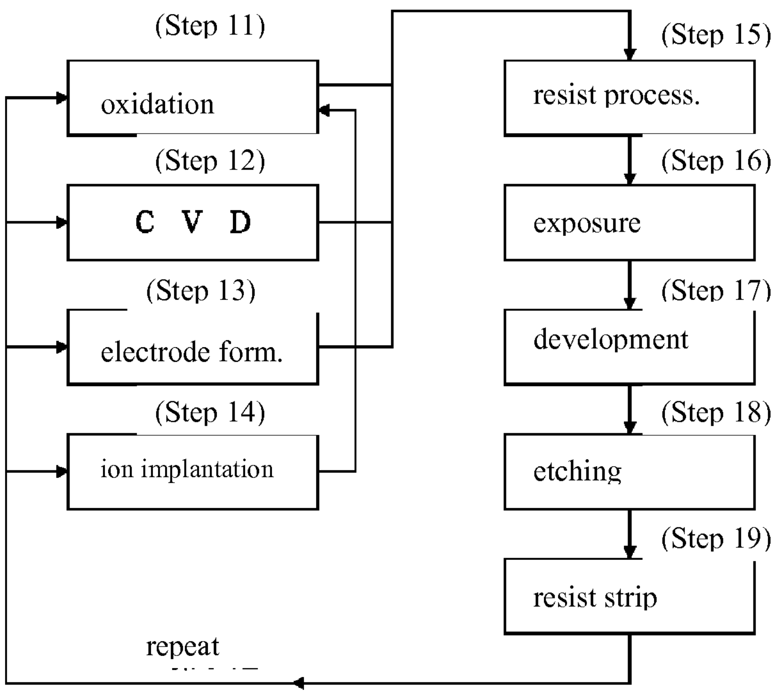


Fig. 26

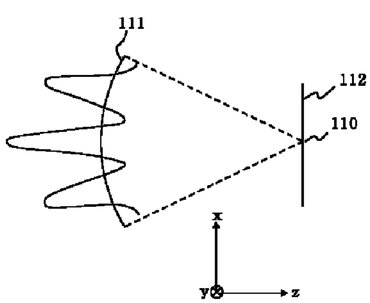


Fig. 27

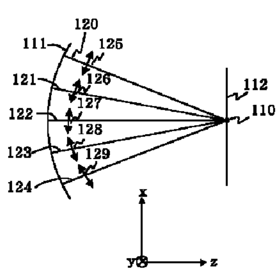


Fig. 28

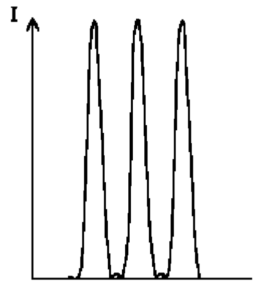


Fig. 29

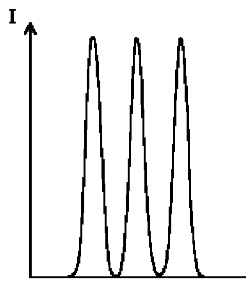


Fig. 30

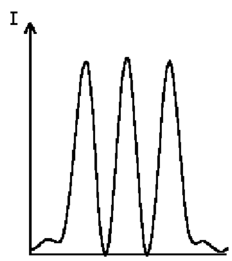


Fig. 31

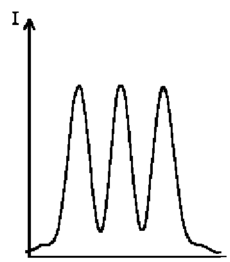


Fig. 32

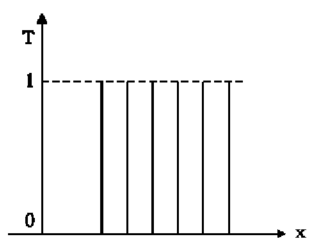


Fig. 33

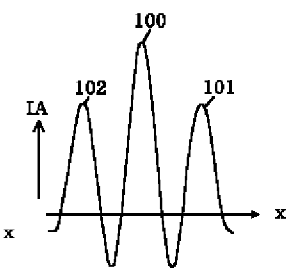


Fig. 34

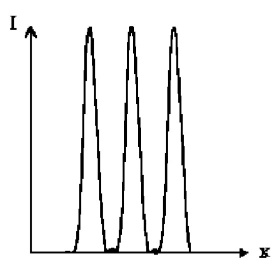


Fig. 35

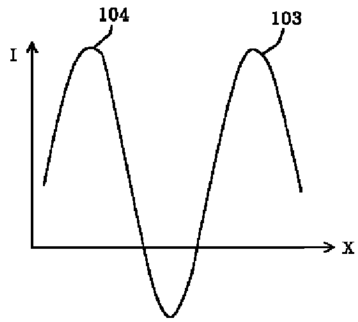


Fig. 36